



Remembering the Past from the Depths of Space

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3rd Annual Non-Volatile Memory Symposium



Acknowledgment

Much of this information was derived from the
draft version of the

New Frontiers in the Solar System

An Integrated Exploration Strategy

by the Space Studies Board of the National
Research Council and supporting mission
studies



Context

- Chartered to survey the subject of what is already known and to create an integrated strategy for future solar system exploration
- Key themes identified:
 - The First Billion Years of Solar System History
 - Volatiles and Organics: The Stuff of Life
 - The Origin and Evolution of Habitable Worlds
 - Processes: How Planets Work



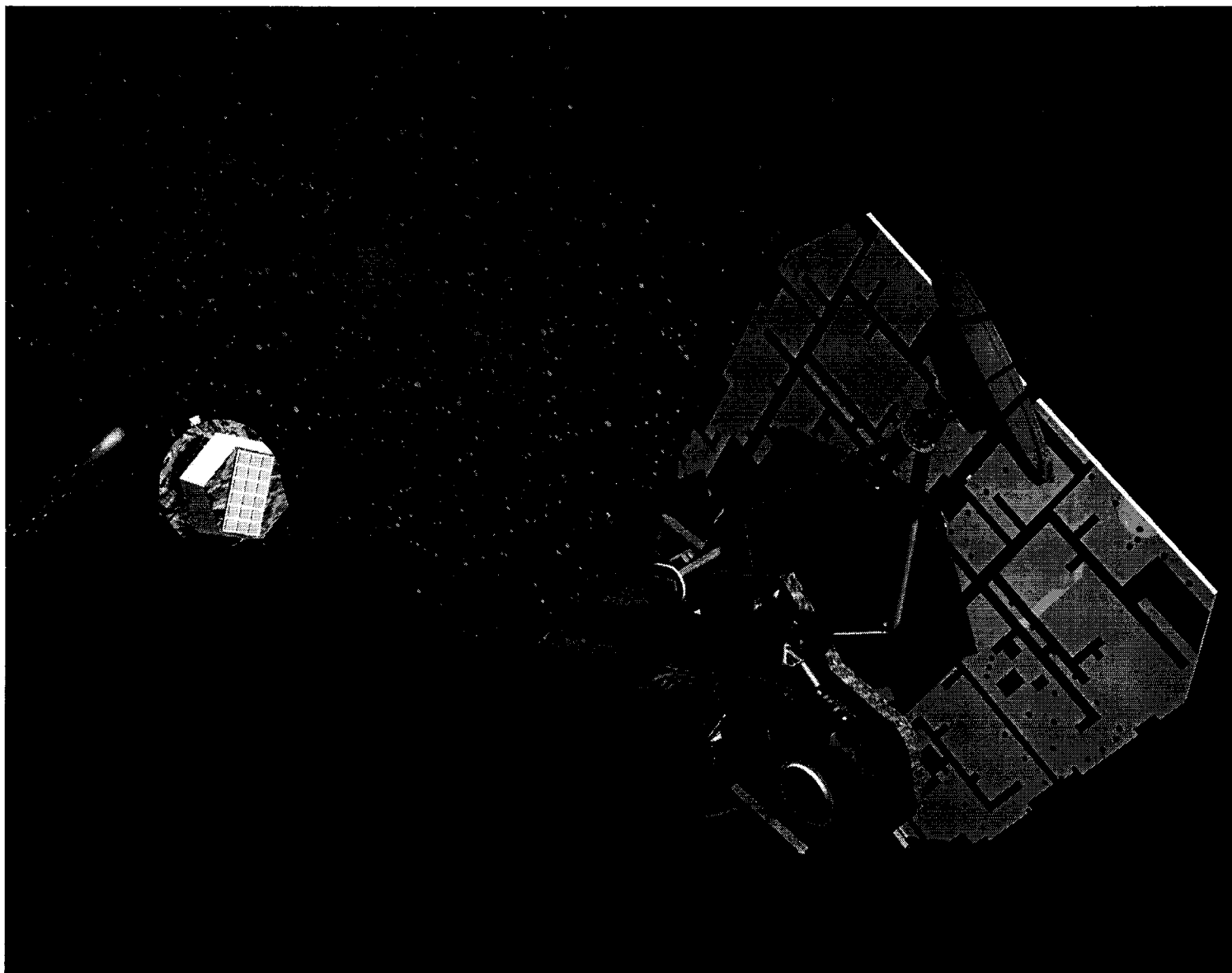
Context

- Example missions were identified to address these themes
 - Some are doable with today's technology
 - Some require near term technology
 - Some require significant advances in technology
- The exploration of the solar system is a technically challenging and expensive endeavor.



Deep Impact

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Deep Impact Mission

- Catch up with Comet Tempel 1 on July 4, 2005
- Send 370 kg probe to impact surface
- Observes and records data from material dissipated into space and fresh material exposed on surface
- Mission duration 19 months
 - Science portion 1-2 days
 - Data return 30 days



Dawn spacecraft - courtesy Orbital Sciences Corp.

JPL





Dawn Mission

- Visiting 2 protoplanets in search of the role of size and water in determining the evolution of the planets
- 11 month orbital period around each of Vesta and Ceres



Landers/Probes

- Landers and Probes are used for extreme environments
 - Temperature – Venus
 - Radiation - IO/Europa
 - Pressure – Jupiter
 - Shock – Deep Space 2 (Mars)

Outer Planets
Multiprobes

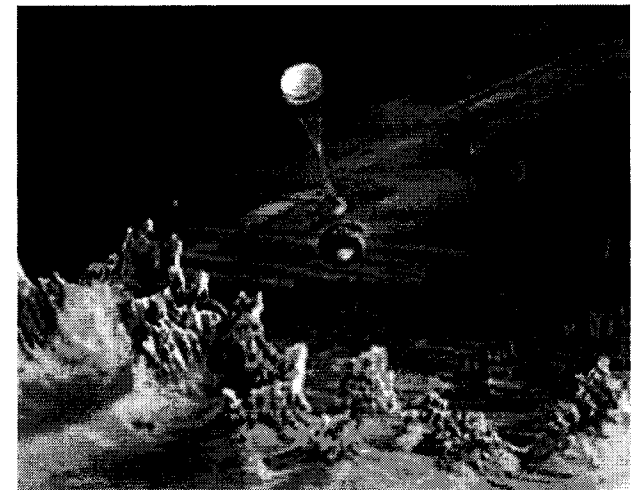




Landers/Probes

- Dumb landing/
decending systems –
Air Bags: Mars
Pathfinder, Parachute:
Huygens, Galileo Probe
- Smart landing/
descending systems –
Rocket Descent: Mars
98, Viking, Mars
Science Laboratory

Huygens - Titan

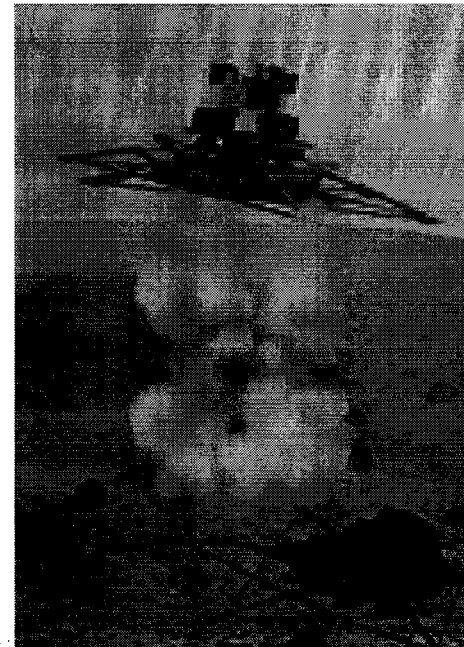




Landers/Probes

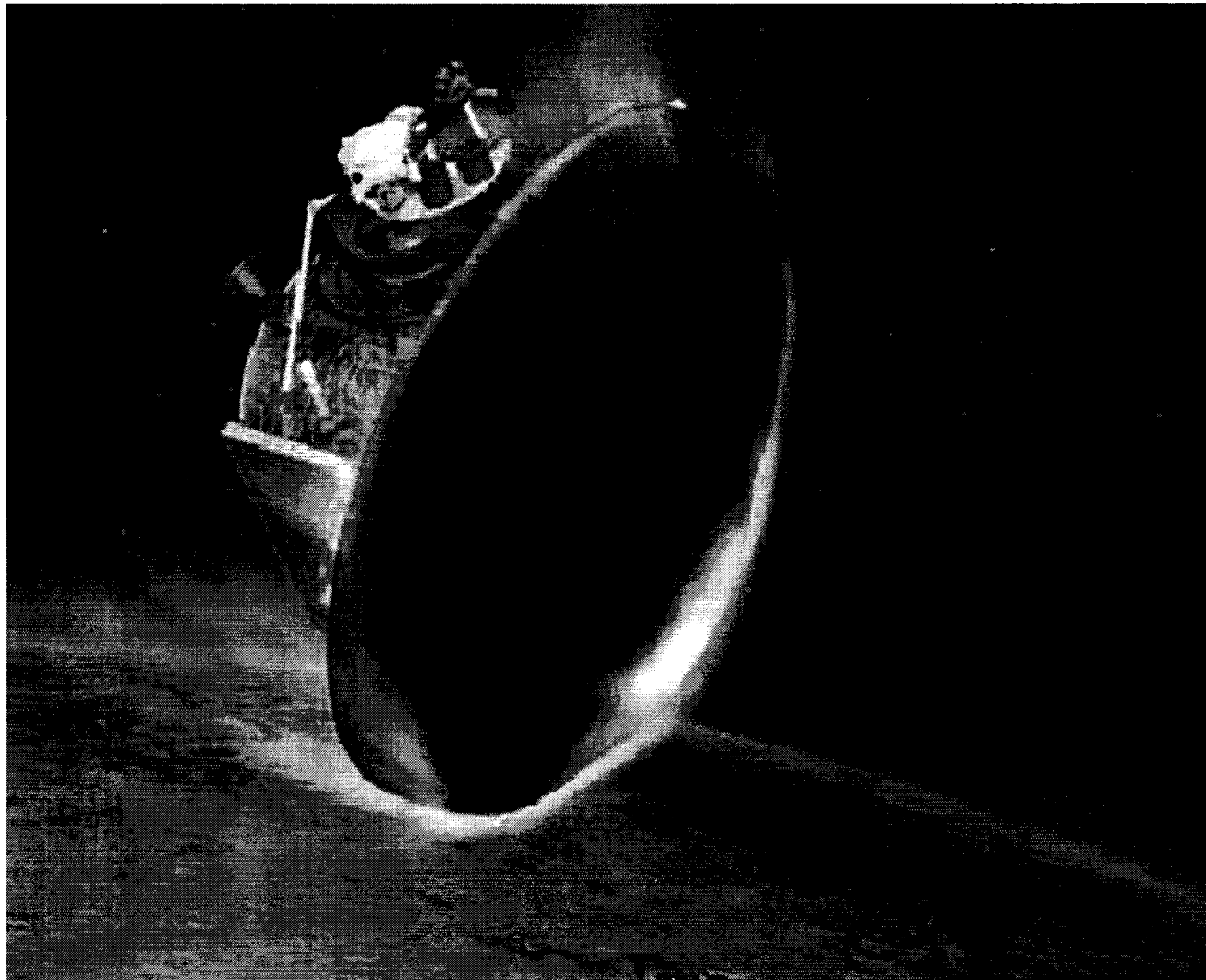
- Landers and Probes are extremely volume, power and mass constrained
- Usually have to relay data to mothership such as an orbiter
- Small buffers for science data storage and computer processing
- Must survive environmental requirements

Smart Lander





Neptune & Triton Missions

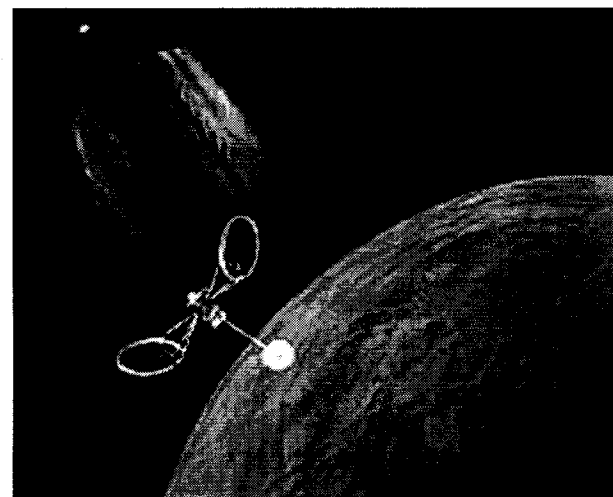




Flyby Missions

- Large flyby velocities
 - data acquired very rapidly
 - Little time for data compression during acquisition
 - Attitude control for maneuvering during science acquisition is computer intensive
- On-board data storage required to hold data until it can be returned after flyby

Europa Flyby

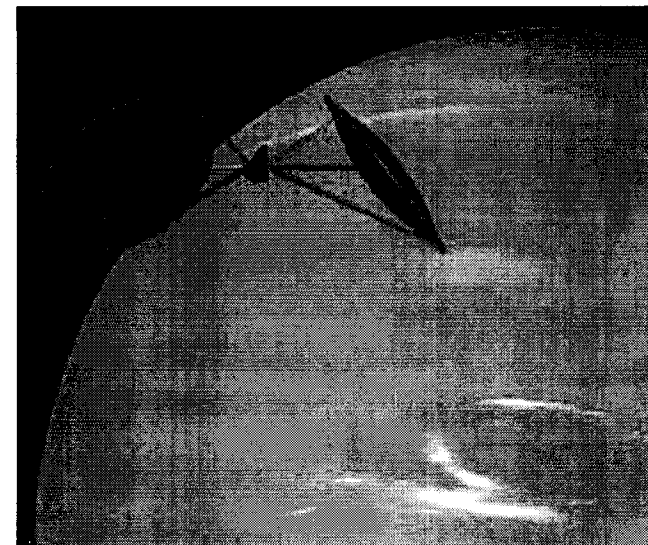




Orbiters

- Long one way light time
- Data return limited by telecommunications state-of-the-art
 - State of the art gets about 1 Mb/s from 6 AU
- Deep Space Network a shared resource
- Further distances severely limit rate requiring more data stored on board until it can be returned

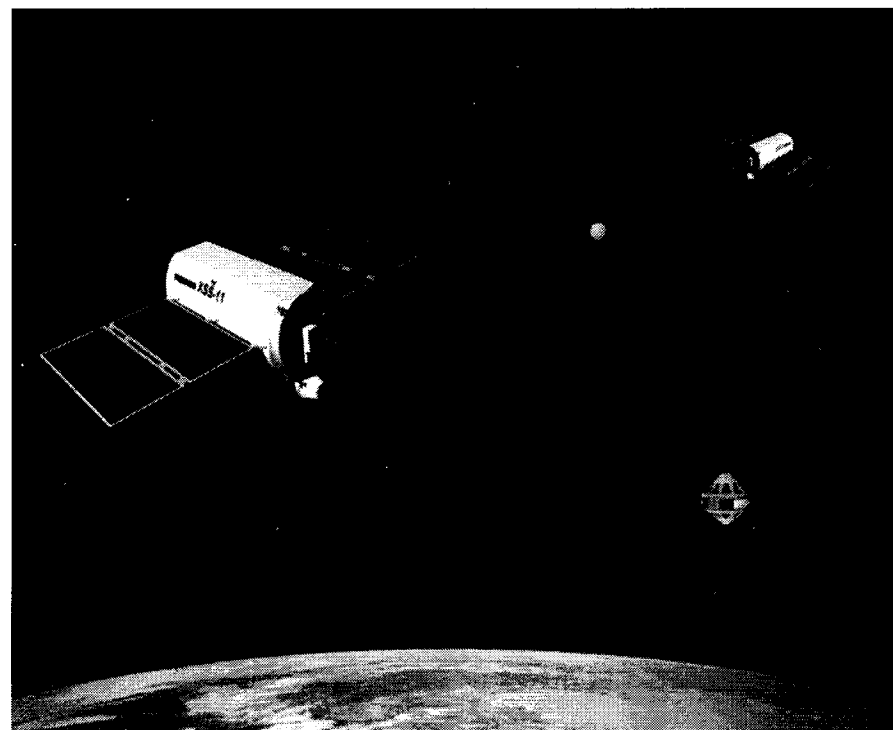
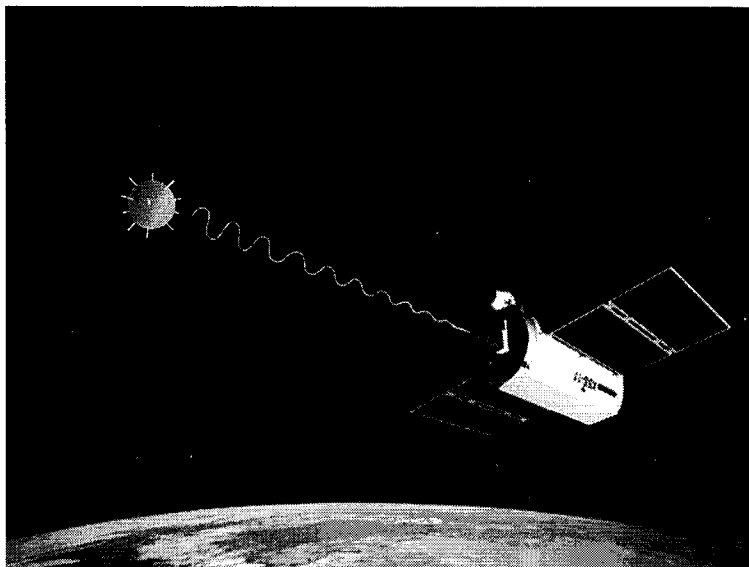
Neptune Orbiter





Space Technology 6 - Autonomous Rendezvous LEO

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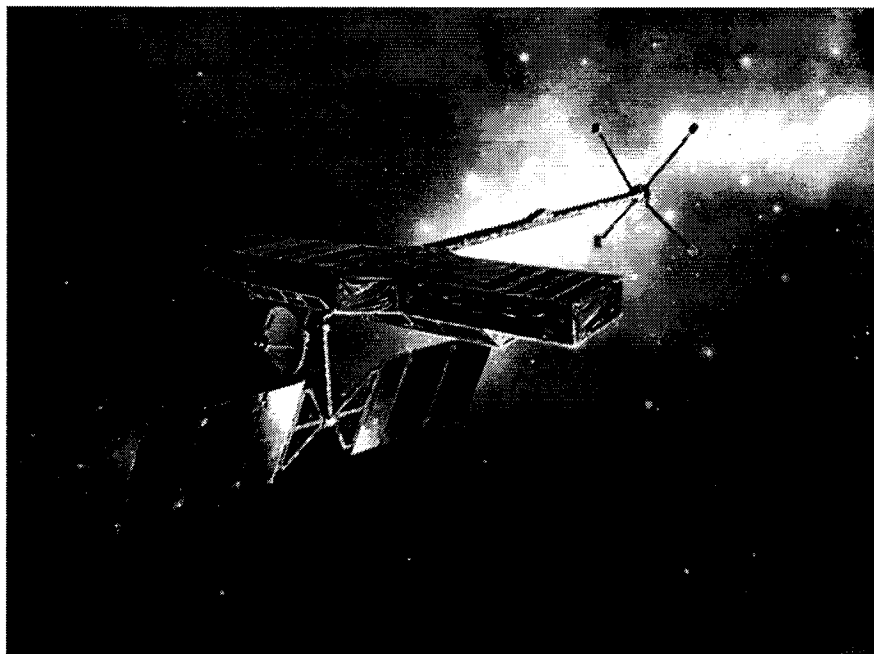


On-Board Autonomy

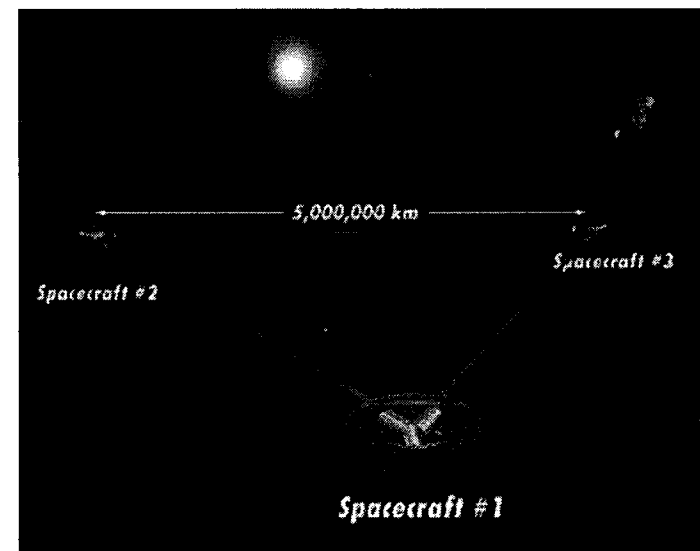
- Entry-Descent-Landing requires intense computer resources
 - Extensive data taking and reconciliation by computer algorithms require fast memory access times
- Rendezvous and docking requires tight control loops for attitude control with stored
- Interferometry requires precise tracking and position determination



SIM



LISA





Environmental Factors

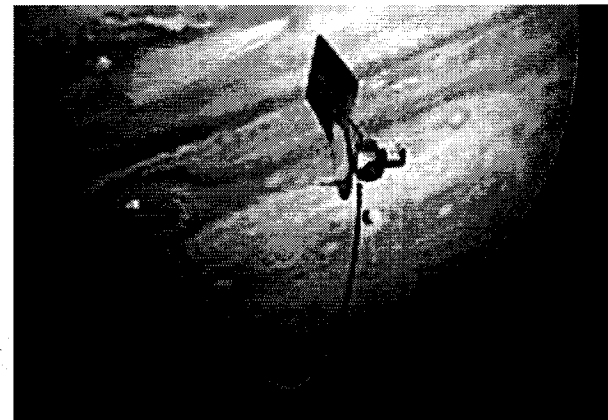
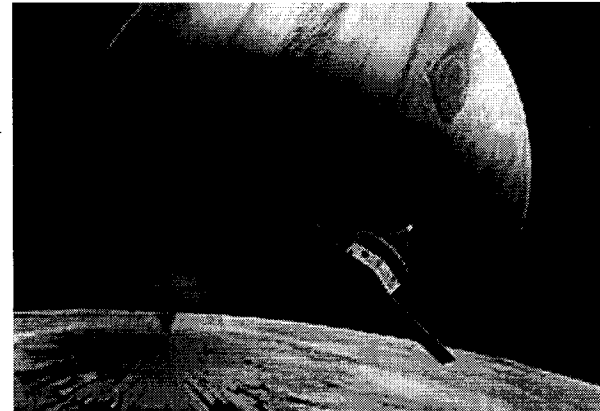
- Solar Flares and Galactic Cosmic Ray environments create havoc for memory data retention and data integrity
 - SEEs and SEUs drive computer system reset rates and mass memory system EDAC requirements
- Missions to the Jovian systems require radiation tolerance or hardness
 - 100 Krad tolerable
 - 1 Mrad much better
 - Example – FLASH for mass memory on Europa Orbiter required approximately 4 kg Tungsten/Copper shielding per 2 Gbit



Jupiter Orbiters

- Jovian system of high import to planetary science community
- Environment harsh for memory systems
- Large operations teams required to effectively compensate for on-board anomaly

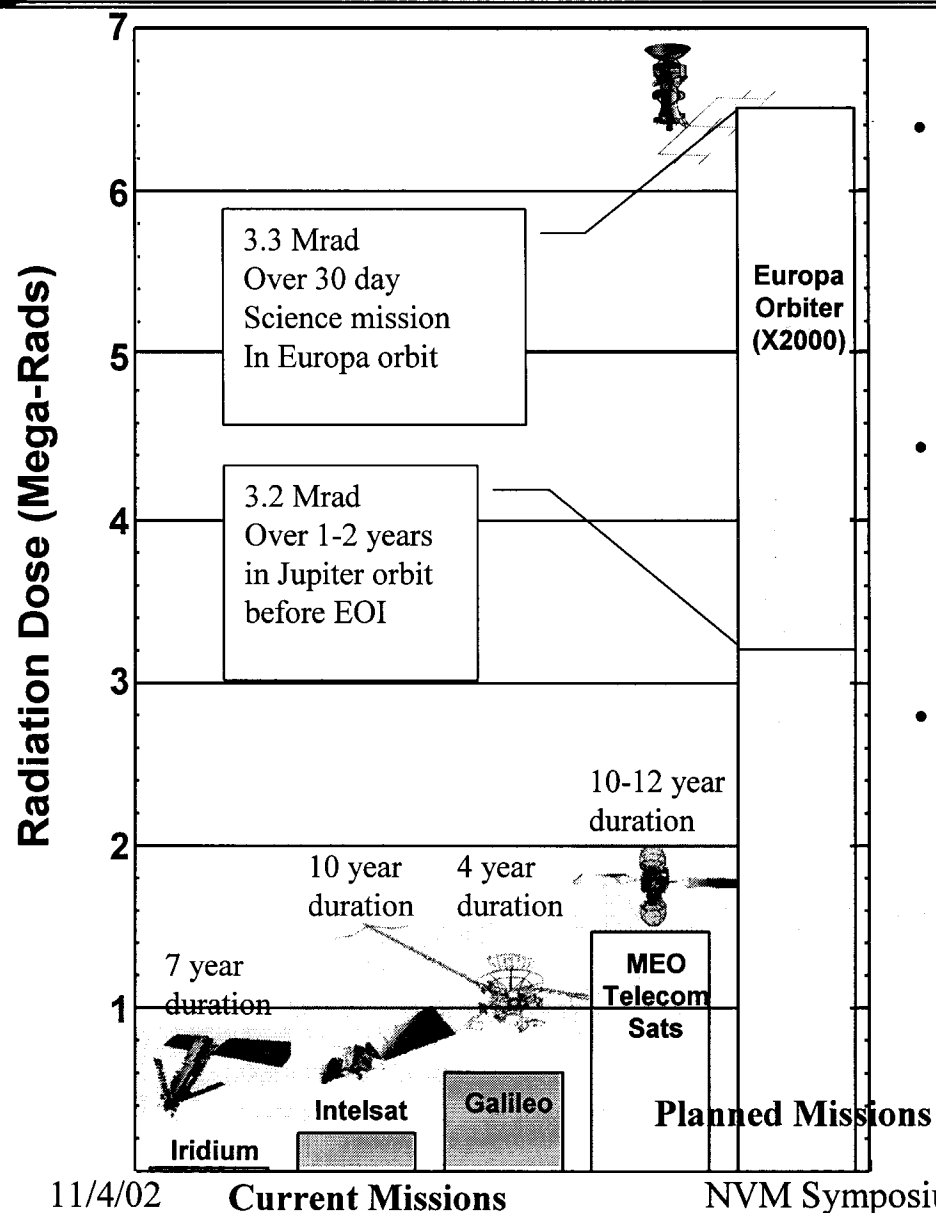
Io Volcano Orbiter



Jupiter Polar Orbiter



EO Mission Radiation Environment



- The Europa Orbiter total dose environment is harsh compared to current experience
 - At Europa an astronaut inside an EVA suit receives a lethal dose every 12 minutes
- The Europa Orbiter must operate with high reliability during the 30 day mission
 - Science objectives
 - Achieve quarantine orbit
- Impact
 - High technology, high risk, high cost electronics development to reduce risk



Environmental Factors

- Many mass memory chips only available from commercial manufacturing lines
 - Lose insight into manufacturing processes
 - Not consistent from lot to lot
 - No traceability to investigate failures
 - Less stringent screening and life testing requirements

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Data Storage Technologies



A Small Historical Perspective

<u>Item</u>	<u>MGN</u>	<u>CAS</u>	<u>MPF</u>	<u>X2000</u>
Cap.	1.8Gb	2.5Gb	2Mb	2Gb
Media	Tape	DRAM	EPROM	Flash
Qty	1 / 3 <u>Mile</u>	640	80	20
Pwr	35W, 28V	12W, 28V	7W, 5,12V	3W, 3.3V
Mass	22kg	17kg	4kg	<u>220g</u> 1.7kg (shield)
Size	16x12x8 (inches)	16x8x7 (inches)	6U VME (2 cards)	3U PCI
VOLATILE	N	<u>Y</u>	N	N



Data Storage Technologies

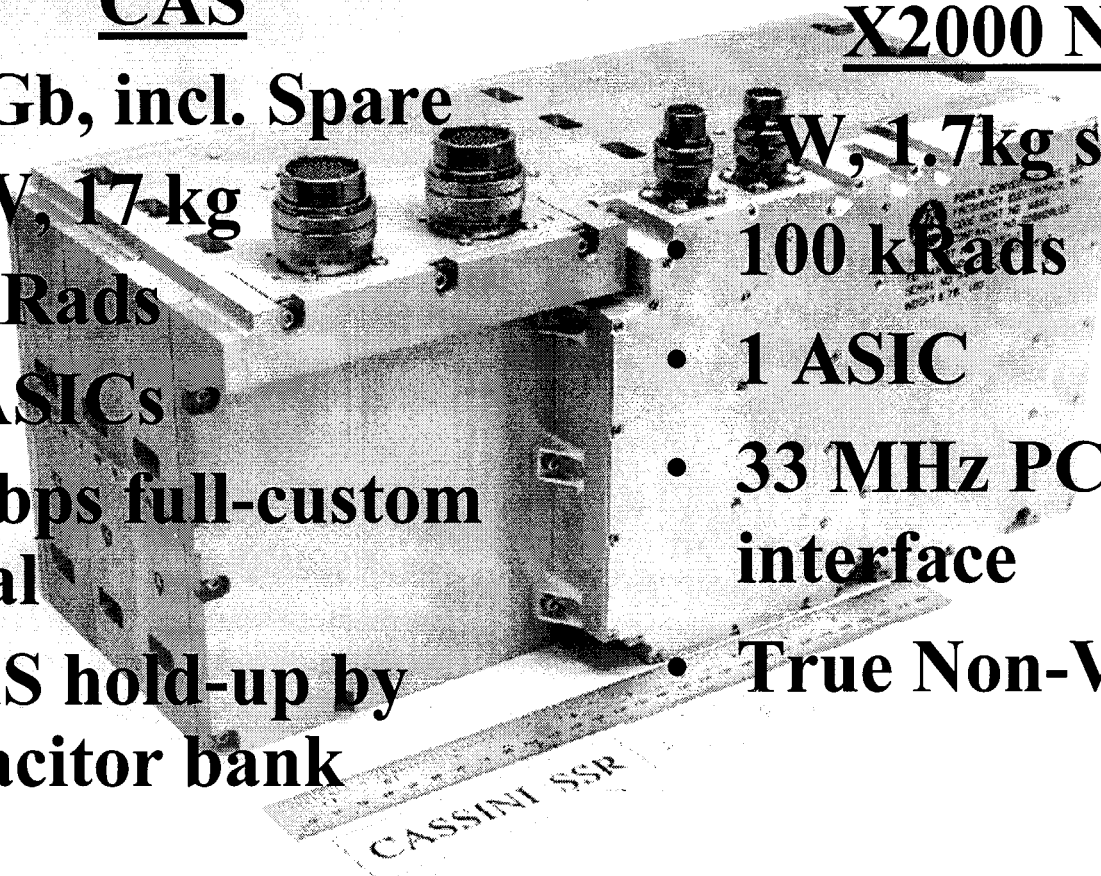


CAS

- 2.5 Gb, incl. Spare
- 12 W, 17 kg
- 20 kRads
- 18 ASICs
- 1 Mbps full-custom serial
- 35mS hold-up by capacitor bank

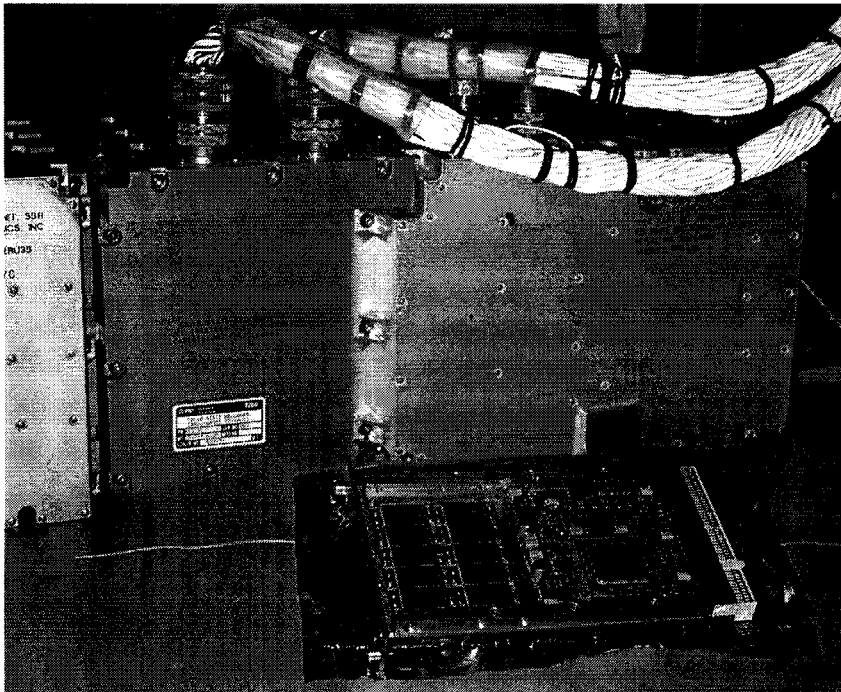
X2000 NVM

- 12 W, 1.7kg shielded
- 100 kRads
- 1 ASIC
- 33 MHz PCI interface
- True Non-Volatility





A Comparison of Generations



< Cassini SSR

17 kg, 12W, Volatile

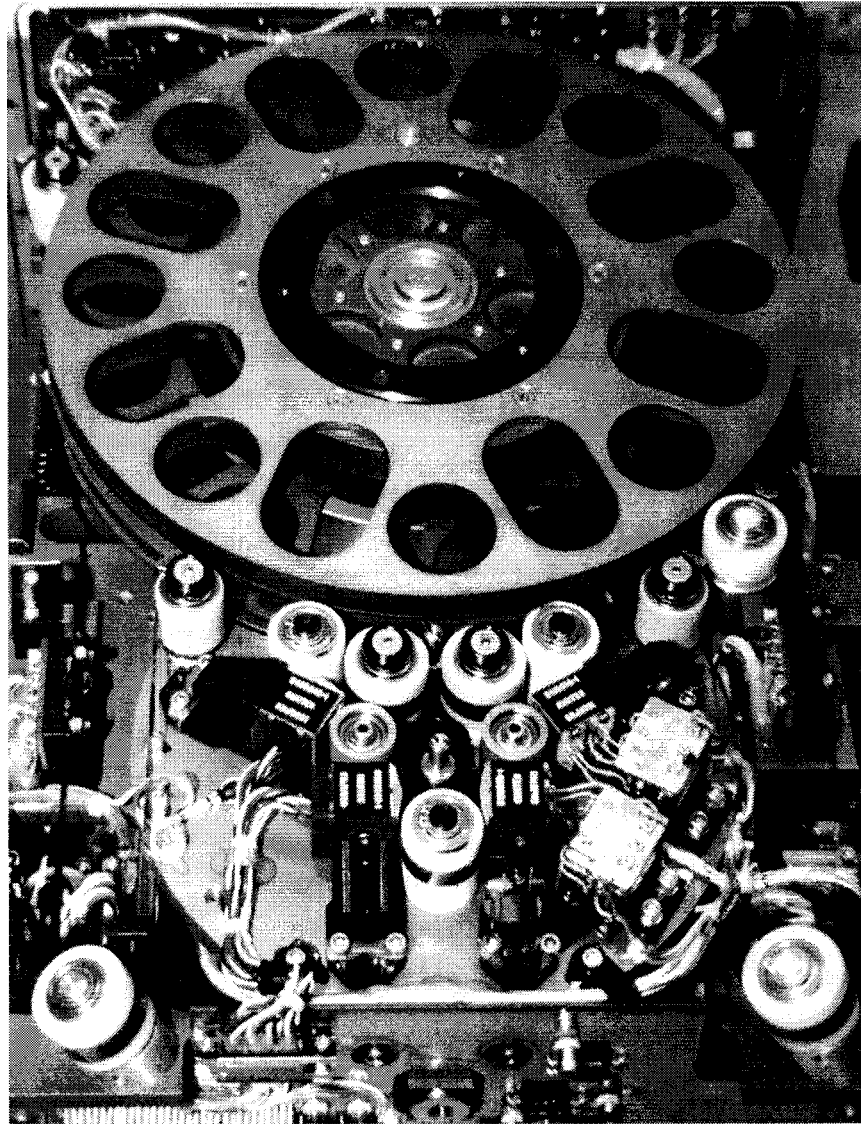
< X2000 NVMS

220g (unshielded), 3W,
NONVOLATILE



Prior Art: GLL & MGN Recorder

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Major Drivers

- Mass/Density
 - Space missions are constrained by current launch capabilities – what can be launched
 - Defined by orbital mechanics
 - Can directly effect flight time to target
 - Always severely mass constrained
 - The less engineering systems weigh, the more science for the dollars
 - Orbiting bodies or landing masses require significant amounts of infrastructure mass



Major Drivers

- Power
 - Solar power drops off as square of distant from sun
 - Nuclear power required for some missions
 - Therefore, deep space missions require low power electronics
- Volume
 - Constrained by launch vehicle shroud
 - Ultimately translates to mass or performance



Major Drivers

- Speed
 - Access time extremely important to get best performance from processors
- Radiation/SEE performance
 - Jupiter deemed important target, need radiation tolerant/hard electronics
 - Deep space missions need to endure GCR and solar flares



Future Needs

- Consistent Space Product
 - High quality
 - Proven life
 - Predictable behavior
- Low Cost
 - Mass production
 - Pin-for-pin replacements for current product



Future Needs

- Super Dense Volatile Memories
 - Fast access time
 - Radiation hardened
 - Keep pace with computer processor improvements
- Dense Non-Volatile Memories
 - Prime science data storage
 - Low power
 - Large read/write cycles for long mission engineering data storage
 - Radiation hardened



MER Rover

